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Original Article

Optimising human community sizes

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ABSTRACT

We examine community longevity as a function of group size in three historical, small scale agricultural samples. Community sizes of 50, 150 and 500 are disproportionately more common than other sizes; they also have greater longevity. These values mirror the natural layerings in hunter-gatherer societies and contemporary personal networks. In addition, a religious ideology seems to play an important role in allowing larger communities to maintain greater cohesion for longer than a strictly secular ideology does. The differences in optimal community size may reflect the demands of different ecologies, economies and social contexts, but, as yet, we have no explanation as to why these numbers seem to function socially so much more effectively than other values.

1. Introduction

Although humans are capable of living in structurally diverse societies, our communities, even in the digital world, have a distinctive layered structure with successive cumulative layer sizes of 15, 50, 150, 500 and 1500 (Fuchs, Sornette, & Thurner, 2014; Hamilton, Milne, Walker, Burger, & Brown, 2007; Zhou, Sornette, Hill, & Dunbar, 2005). While the smallest of these is not normally a stand-alone grouping, the others appear as natural community sizes in hunter-gatherer societies: Lehmann, Lee, and Dunbar (2014) give values of 42.8 ± 18.0SD (bands), 127.3 ± 43.8 (clans), 566.6 ± 166.2 (mega-bands) and 1727.9 ± 620.6 (tribes) for 20 contemporary hunter-gatherer societies (see also Hamilton et al., 2007; Zhou et al., 2005). These values reappear in both offline and online egocentric social networks (Hill & Dunbar, 2003; Sutcliffe, Dunbar, Binder, & Arrow, 2012; Dunbar, Arnaboldi, Conti, & Passarella, 2015; Arnaboldi, Passarella, Conti, & Dunbar, 2015; Dunbar, 2016; MacCarron, Kaski, & Dunbar, 2016), which are characterised by distinct layers that represent quite specific frequencies of interaction and levels of emotional closeness (Roberts, Dunbar, Pollet, & Kuppens, 2009), reflecting the levels of intimacy that individuals maintain with each other. Even more surprisingly, perhaps, Kordsmeyer, MacCarron, and Dunbar (2017) found that the sizes of residential campsites in contemporary Germany also adhere to these values.

This fractal structure suggests that there might be natural fission points that result in organisations having distinct sizes, with these representing optimal values that maximise some quantity such as coherence, and hence stability through time. Optimal community size will, of course, ultimately be determined by the functional demands of the socio-ecological environment (Dunbar, Korstjens, & Lehmann, 2009). However, the question arises as to whether there are natural "sweet spots" at which communities are likely to be more successful (i.e. survive longer without fissioning) because they map better onto natural grouping patterns and their underpinning psychology.

We test this possibility using historical datasets from three types of collectivist societies: 19th century American utopian communes, Hutterite colonies of South Dakota (USA), and Israeli kibbutzim (for details, see ESM). Although their economic and political circumstances vary widely, all involve small scale agricultural communities established to be self-sufficient within a communal ideology. Like all primate social groups, human communities are not fixed in size, but grow dynamically over time so long as births exceed deaths; once they reach a limiting size set by their local ecology, they then fission, resulting in a cyclic pattern of slow growth followed by sudden collapse (Dunbar et al., 2009; Dunbar, MacCarron, & Robertson, submitted). Our central question, then, is: do such communities have an optimal size, and how does size affect community survival and longevity? We use the mean layer values for hunter-gatherer societies (given above) as our benchmark for comparison.

2. Methods

We use two datasets on community sizes compiled by RS and colleagues. One collates data on C19th American utopian communities, based on Oved (1988), which has previously been used in a number of analyses (Sosis, 2000; Sosis & Bressler, 2003); the other collates data

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on the size and duration of Israeli kibbutzim, based on Ben-Rafael (1997) and Pavin (2007). Of the 83 communes in the US database, size at foundation and duration are known for 53 (21 religious foundations and 32 secular foundations). There are 240 kibbutzim in the Israeli database, with foundation date and current size known for each. Although date of foundation is known for both datasets, size at foundation is available only for the American utopian communes; only the current community size (as of a 2005 census date) is available for the Israeli kibbutzim.

We also use data on Hutterite community fission events covering the period 1880–1970 given by Olsen (1987). This dataset includes the community size at fission, and the sizes of the resulting daughter communities, for two colonies (*leuts*) of South Dakota Hutterites (the Schmiedenleut and the Lehrerleut) for all but a handful of fission events. The two *leuts* are named after their founding fathers, and have led separate existences since the 1870s. In all, data are available for 48 fissions in the Lehrerleut and 49 fissions in the Schmiedenleut (with no data on community sizes for an additional six fission events). When fission occurs, one daughter community remains on the community's farm and the other starts a new colony on new land. The Hutterites are a natural fertility population, and population growth rates are high (4.5% per annum in the Schmiedenleut and 4.1% the Lehrerleut), with the interval between successive fission events averaging 14.3 years (range 4–39 years). The dataset represents a total population of 12,470 individuals.

The data are available in the ESM.

The data on community size are typically highly skewed, with long tails to the right. For this reason we use geometric means, which are more appropriate when data are skewed. Our main statistical analysis involves two steps for each dataset. First, we use k-means cluster analysis to determine the optimal number of clusters that best describe the data. We run the cluster analysis for successive values of $k = 2 \ldots n$ and search for the value of k that maximizes the goodness of fit (indexed by the analysis of variance F-statistic) or at which F reaches an asymptote. This gives us the optimal number of clusters that best describe the data and the mean size of each cluster. Second, we ask whether the mean values so identified approximate the observed values for hunter-gatherer social groupings (as identified by Lehmann et al., 2014) and the adjacent sympathy group layer of personal social networks (Hill & Dunbar, 2003). For these purposes, we calculate the difference between each of these 'theoretical' values and the observed value as a standardized normal deviate, computed in the usual way as $z = (N_{obs} - N_{HG(i)}) / SD_{HG(i)}$, where N_{obs} is the observed mean group size, $N_{HG(i)}$ the mean size of the level *i* grouping in hunter-gatherers (where *i* identifies band, clan, etc.), and $SD_{HG(i)}$ the standard deviation for that grouping. We compare each cluster mean with the values for each of the four hunter-gatherer grouping layers in turn in order to identify the layer to which the observed value corresponds most closely. For these purposes, we seek the p-value closest to $p = 1.0$ (i.e. z closest to 0), subject to the proviso that $p > 0.05$ (i.e. the observed value is not significantly different from the theoretical value). We confirm the result with a model selection procedure, using BIC as our criterion.

In certain cases, we undertake regression analyses. We use a detrended analysis, a procedure commonly used in demography and conservation biology (for examples, see Cowlishaw & Dunbar, 2000) to standardise group size when populations are at different stages of their natural lifecycle. A detrended analysis plots the residual of group size regressed on time against another variable of interest. The second procedure is quantile regression, which is used in conservation biology and other areas to derive a regression equation for upper or lower bounds (i.e. where data are subject to an upper or lower limit). To do this, the X-axis is partitioned into, typically, 10 equal divisions; the highest (or lowest) Y-axis value is then identified in each division, and a regression set through these values (Blackburn, Lawton, & Perry, 1992).

3. Results

3.1. C19th US communes

Fig. 1a shows the size at foundation for 53 C19th American utopian communes. We plot the data on a log-scale because they have a strong skew with a long right tail. Excluding the extreme righthand datapoint (the rather unusual Zion City community, size = 5000, 31 standard deviations from the sample mean), the geometric mean size at foundation is 52.4 ± 87.1SD. This most closely approximates the hunter-gatherer band layer (Table 1). A *k*-means cluster analysis of the raw values yields an optimal division into three clusters (fewer or more clusters yield significantly lower fits) with cluster means at 49 (41 communities) and 268 (9 communities), with two communities centred at 700 ($F_{2,49} = 197.49$, $p \ll 0.0001$). These values equate best with, respectively, the band and mega-band layers of hunter-gatherer society (Table 1). There are no significant differences between religious and secular communities.

Plotting community survival against size at foundation (Fig. 1b) allows two important conclusions to be drawn. First, religious communities survived significantly longer than secular ones (on average, 35.6 ±

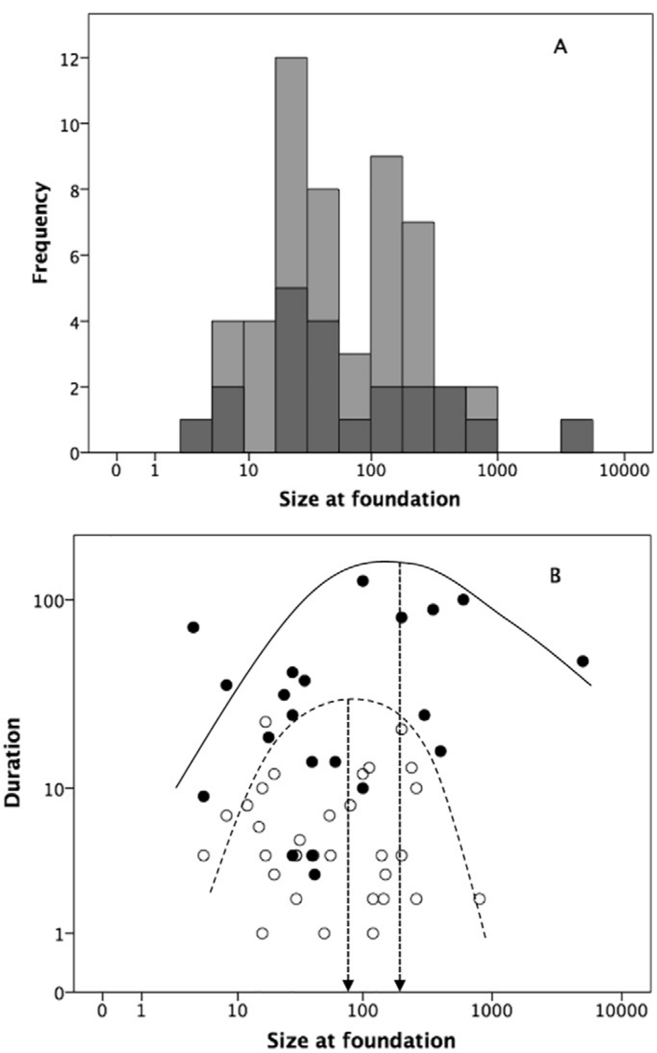

Fig. 1. (a) Size at foundation of 53 C19th US utopian communes. All but one (Zion City at 5000 members) were <1000 in size. Dark: religious communes; light: secular communes. (b) Commune duration plotted against size at foundation for religious (solid symbols, solid line) and secular (open symbols, dashed line) communes. Regression lines are quantile regressions on the upper bounds, and the vertical lines indicate foundation sizes that maximise longevity.

Table 1
Statistical analysis of grouping sizes identified in the main text against the sympathy group and the three main layers of hunter-gatherer societies.

Mean group size		Comparison* against			
		Sympathy group	Band	Clan	Megaband
		11.3 ± 6.19SD[a]	42.8 ± 18.0SD[b]	127.3 ± 43.8[b]	566.6 ± 166.2[b]
C19th US communes					
Mean size	52.4	$z = 6.93, p < 0.0001$	$\mathbf{z = 0.53, p = 0.596}$	$z = -1.67, p = 0.095$	$z = -3.09, p = 0.002$
Cluster sizes	49	$z = 6.09, p < 0.0001$	$\mathbf{z = 0.34, p = 0.734}$	$z = -1.79, p = 0.074$	$z = -3.11, p = 0.002$
	278	$z = 43.09, p << 0.0001$	$z = 13.07, p << 0.0001$	$z = 3.44, p = 0.001$	$\mathbf{z = -1.74, p = 0.082}$
	700	$z = 111.3, p << 0.0001$	$z = 36.51, p << 0.0001$	$z = 13.08, p << 0.001$	$\mathbf{z = 0.80, p = 0.424}$
Optimal size for longevity					
Secular	64.4	$z = 8.58, p < 0.0001$	$\mathbf{z = 1.20, p = 0.230}$	$z = -1.44, p = 0.150$	$z = -3.02, p = 0.003$
Religious	171.1	$z = 25.86\ p << 0.0001$	$z = 7.13, p < 0.0001$	$\mathbf{z = 1.00, p = 0.317}$	$z = -2.38, p = 0.017$
US Hutterites					
Mean size at fission	166.5	$z = 25.07, p << 0.0001$	$z = 6.87, p < 0.0001$	$\mathbf{z = 0.89\ p = 0.374}$	$z = -2.41, p = 0.016$
Optimal size for longevity	50	$z = 6.25, p < 0.0001$	$\mathbf{z = 0.40, p = 0.689}$	$z = -1.76, p = 0.078$	$z = -3.11, p = 0.002$
	150	$z = 22.41, p << 0.0001$	$z = 5.96, p < 0.0001$	$\mathbf{z = -0.52, p = 0.603}$	$z = -2.51, p = 0.012$
Israeli Kibbutzim					
Mean size	468.2	$z = 73.81, p << 0.0001$	$z = 23.63, p << 0.001$	$z = 7.78, p < 0.0001$	$\mathbf{z = -0.59, p = 0.555}$
Minimum foundation size	~150	$z = 22.41, p << 0.0001$	$z = 5.96, p < 0.0001$	$\mathbf{z = 0.52, p = 0.603}$	$z = -2.51, p = 0.012$

* The statistical test is whether the observed mean value is < 1.95 standard deviations of the mean value for a given hunter-gatherer grouping, given the SD for that grouping (i.e. if p > 0.05, the observed value does not differ significantly from the theoretical value). **Bolded** values identify most likely equivalent social layer, based on model comparison using BIC.
[a] From Hill and Dunbar (2003).
[b] From Lehmann et al. (2014).

32.5SD vs 7.7 ± 8.0 years: $F_{1,81} = 35.5$, $p < 0.001$). Second, the two types of community differ in the optima at which duration is maximised. Setting upper bounds to these distributions by quantile regression and then setting the first derivative to zero to find the maxima yields community sizes that maximise longevity of 64.4 and 171.1, respectively, for secular and religious communities (with corresponding mean durations of 15 and 100 years). These values mirror the band and clan levels of hunter-gatherer societies (Table 1). In sum, communities of around 50 or 150 at foundation seem to survive longer than those at other values.

3.2. Hutterite communities

Fig. 2a plots the size at fission for 97 fission events that occurred in the two Hutterite *leuts* over a 90-year period. In this case, the distribution is approximately normal, with mean size at fission of 166.5 ± 25.8SD: this most closely approximates the hunter-gatherer clan layer (Table 1). The two *leuts* do not differ in average size at fission (165.7 ± 22.2 vs 167.3 ± 29.1: $F_{1,95} = 0.095$, $p = 0.759$). A *k*-means cluster analysis indicates that this consists of two clusters with means at 147 and 189 ($F_{1,94} = 196.49$, $p \ll 0.001$; partitioning into three clusters does not yield any improvement in fit). Means sizes of the two daughter communities after fission are 76.0 ± 12.7SD and 91.2 ± 17.1SD, with the smaller half varying between a third and a half of the original community.

There is a significant negative relationship between the size of a community immediately after fission (size at foundation) and its duration (time to the next fission event) (Fig. 2b: $F_{1,94} = 48.25$, $p < 0.0001$). The regression equation suggests that communities of minimum viable size (~40 individuals) are unlikely to last >25 years without fissioning (in the limit, the smallest possible communities would not last >30 years), and communities larger than ~180 would fission so frequently (at least once a year) that they would be socially unstable.

Fig. 2c plots the detrended survival time for a community as a function of its size at foundation. The detrended survival time is the residual of survival time regressed on foundation size so as to remove the linear size-dependent effect in Fig. 2b, allowing us to compare like-for-like. Detrended survival time is quadratically related to size at foundation ($F_{2,93} = 4.65$, $p = 0.012$; a linear regression is not significant: $p = 0.992$). The maxima occur at ~50 and ~150, which do not differ significantly from band and clan layers (Table 1). In other words, when communities are around 100 at fission, they are likely to undergo fission again much sooner than we would expect for their size. Although this may be difficult to achieve (for the reasons we discuss below), it seems that communities of around 50 and 150 at foundation optimize social functioning and longevity.

3.3. Israeli kibbutzim

Fig. 3a plots the size distribution of 240 Israeli kibbutzim, as of a 2005 census date. The distribution is more or less normal but with the usual long right tail. The geometric mean is 468.2. This does not differ significantly from mega-band size in hunter-gatherers (Table 1). Fig. 3b plots individual kibbutz size against date of foundation. These data suggest a minimum size at foundation of 150. The regression line fitted to these data yields a predicted current size of 756 for a kibbutz founded in 1910, equivalent to an intrinsic rate of growth of 2.1% per annum (approximately half that of the Hutterites) against a foundation size of 150 (the dashed horizontal line) and a doubling time of 33 years. Fig. 3c plots the detrended community size: these data suggest that the first ~55 years of a community's life are characterised by steady growth along a linear trajectory, but that after this the variance increases rapidly with roughly equal likelihood that a community would be significantly above or below the trend line. The latter suggests that communities start to leak members, if not actually fission, at a size of $150 * 1.021^{55} \approx 470$, or very close to the observed mean size of 468.

Since all kibbutzim in the dataset have survived and there have been no more than half a dozen fission events in the movement's century-long history (Near, 1997), we cannot compare survival against size or ideology. However, secular kibbutzim have an absolute growth rate that is significantly lower than that for religious kibbutzim (regression slopes, $b_{Sec} = 0.006$ vs $b_{Rel} = 5.53$: $t_{236} = 3.63$, $p = 0.0003$). As a result, religious kibbutzim were, on average, 168.5 individuals larger than predicted for their age, whereas secular kibbutzim were 4.1 individuals *smaller* than expected (Fig. 4: unequal variances $t_{17.5} = 2.37$, $p = 0.030$). This perhaps suggests that religious kibbutzim may be able to keep their communities together better than secular ones, mirroring the finding from the C19th US communes.

4. Discussion

Our analyses of community size in three politically and economically very different small scale social movements suggest that there are optimal sizes for communities that focus on the values of 50, 150 and 500

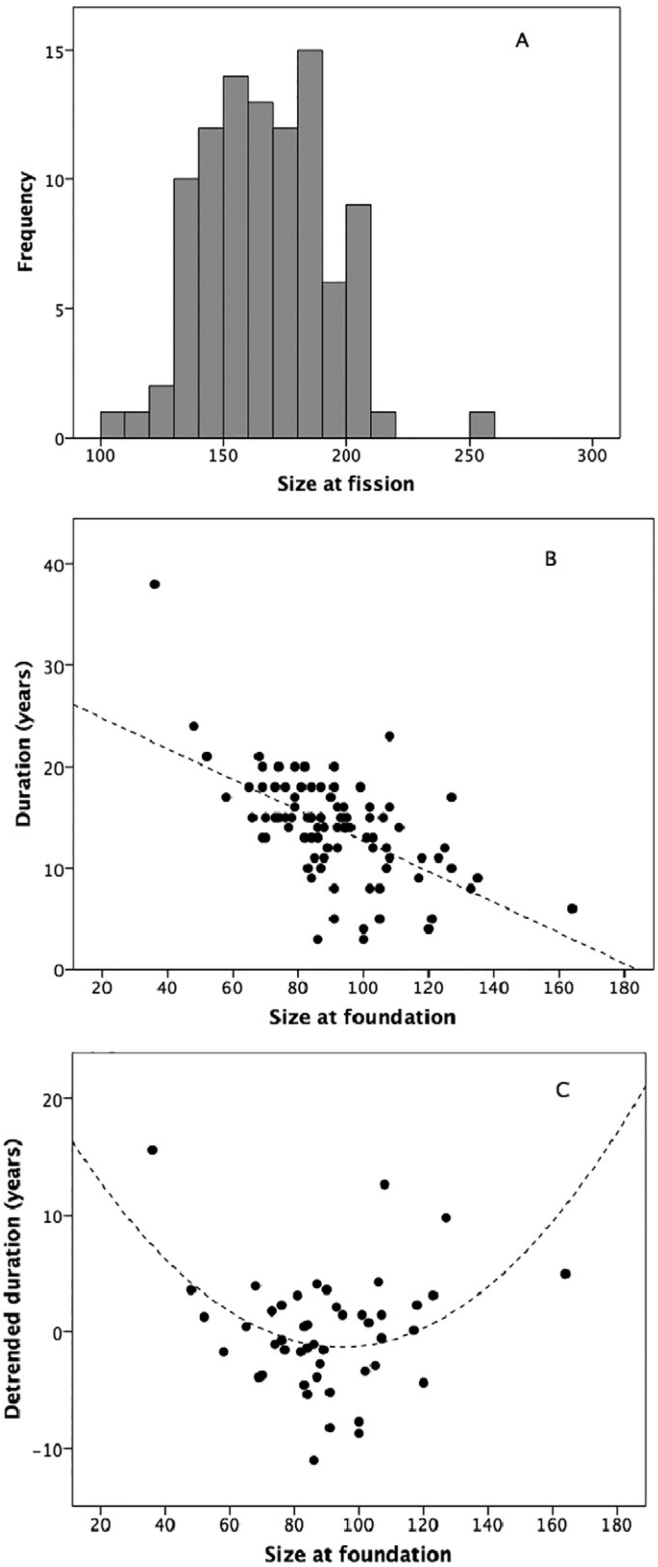

Fig. 2. (a) Size at fission for communities of two US Hutterite *leuts* (lineages) over the period 1880–1970 (N = 97 fission events). (b) Time to next fission event (years) plotted against size at foundation. (c) Detrended duration (deviation of duration above or below the regression line for panel b) plotted against size at foundation. Detrending allows us to control for the differences in size between individual communities when these are subject to natural growth.

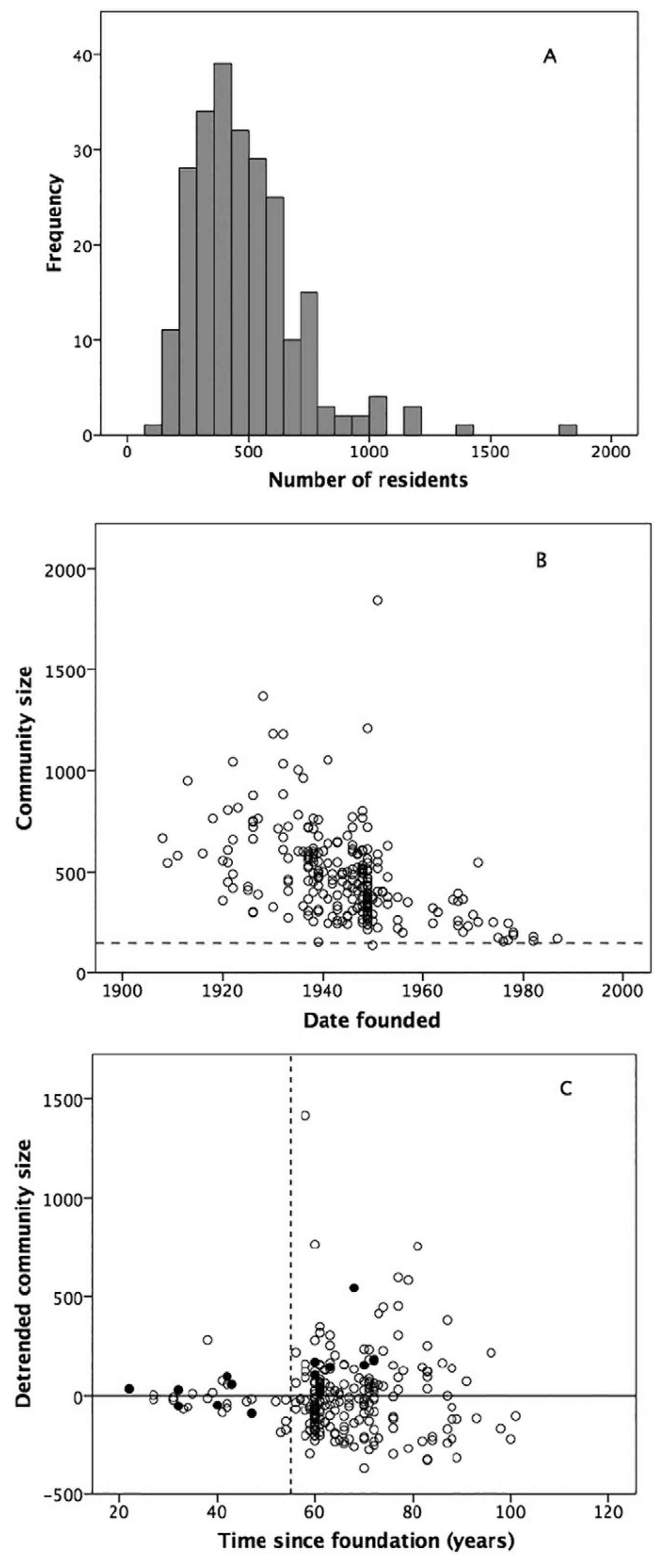

Fig. 3. (a) Size distribution of 240 Israeli kibbutzim as of 2005. Two-thirds of the kibbutzim have <500 residents; only one of the 240 kibbutzim is below 150 in size and only eight (3.8%) are larger than 1000 residents, with the largest being 1366. (b) Current community size plotted against date of foundation for Israeli kibbutzim. (c) Detrended community size (deviation of current size above or below the regression line for panel b) plotted against duration since foundation. Dotted line demarcates the time since foundation after which variance in size increases dramatically. Solid symbols: secular kibbutzim; open symbols: religious kibbutzim.

that have previously been identified in both hunter-gatherer societies and personal social networks (Dunbar, 2011, 2014a, 2014b; Dunbar et al., 2015; Hamilton et al., 2007; MacCarron et al., 2016), as well as elsewhere in the offline and online worlds (Fuchs et al., 2014; Kordsmeyer et al., 2017). Among the historical utopian communities of the C19[th] USA, a size of ~50 or ~150 at foundation seems to have maximised longevity, with communities of other sizes doing less well. Similarly, the Hutterites have historically split their communities once they exceed 150 in size, with the suggestion that daughter communities of ~50 and ~150 last longer without need of further fission than communities that are of intermediate size. In contrast, the Israeli kibbutzim have, in general, not used fission as a means of controlling community size (Abramitzky, 2008, 2011), but nonetheless seem to have a minimum size at foundation of ~150 and a long term stable size of ~500 individuals, apparently mainly as a result of trickle emigration (casual emigration by individuals) once this value is exceeded. The large sizes of kibbutzim may reflect their greater engagement in a more developed commercial economy with need for a larger labour force. Yet, they nonetheless match one of the natural layers found in hunter-gatherer societies.

The Hutterites split their communities once they are above ~150 because, in their experience, this is the limit at which community cohesion can be maintained without the need for formal laws and a police force to maintain discipline (Olsen, 1987). Forge (1972) arrived at a similar conclusion from an analysis of settlement size and structure among New Guinea horticulturalists. He argued that, in these societies, 150 was a key threshold for community size because basic relationships of kinship and affinity were insufficient to maintain social cohesion when a community exceeded this size. It is perhaps relevant that, in natural fertility populations, the community of living descendants of a founding couple five generations back from the current offspring generation (grandparents' grandparents, or about as far back as anyone currently alive will have known personally) is ~150, and that no culture has kinship terms that identify relationships beyond this limit (essentially second cousins) (Dàvid-Barrett & Dunbar, 2017; Dunbar, 1995). In effect, natural kinship classifications seem to be mapped onto the typical size of natural communities. The crucial implication of Forge's observation is that, when community size exceeds ~500, the rising intensity of social and other stresses threaten community coherence and stability, and cohesion can only be maintained if some mechanism is available to suppress or mitigate these disruptive forces (Dunbar, 2012).

Naroll (1956) concluded, from an analysis of maximum village size in 30 small scale societies, that there is a critical threshold at ~500 individuals beyond which social cohesion depends on having a top-down authoritarian organisational structure, associated with the emergence of specialist social, political and economic roles. (It is not clear what the relationship between maximum and mean community size is, but it is noteworthy that Naroll's maximum value threshold corresponds to one of the layers of interest.) While the Hutterites have historically seen hierarchical organisations as one step too far, preferring instead to limit community size by fission so as to manage communities through peer pressure (Olsen, 1987), Israeli kibbutzim have typically responded by reducing the advantages offered by leaving to join the external world (e.g. by allowing merit-based inequalities in salary and out-work, or by hiring external labour for menial tasks) (Abramitzky, 2011) perhaps in order to facilitate a larger workforce on commercial farms. However, intriguingly, secular kibbutzim (which necessarily lack a religious framework to provide a policing function) have responded by increasing levels of surveillance over residents in order to enforce conformity to the kibbutz's ideals: mean detrended community size ($+44.9 \pm 44.9$SE, $N = 38$) is larger for kibbutzim that have surveillance mechanisms than for those that do not (-14.7 ± 13.4SE, $N = 184$) (Fig. 4; $t_{220} = -1.66$, $p = 0.049$ 1-tailed since we test a directional hypothesis).

In bonded societies such as those of humans and many primates, group fission is subject to constraints due to the viability and/or structural stability of small and large groups (Dunbar et al., 2009, submitted). This will often mean that fission has to occur at sizes that are less than ideal. It is clear that the Hutterites face this problem: ideally, they would like to split their communities at 150 for reasons of structural coherence, but at the same time daughter groups that approximate 50 and 150 are likely to be more stable than those in between. In addition, there is presumably a minimum viable size for a community to function as an agricultural enterprise (around 45–50 individuals, judging by the minimum size of the smaller daughter groups). Splitting a community of 150 into a 50 and a 100 would yield one unstable community and a stable but minimally viable one, while an even split into two 75s would yield two economically more viable, but socially less stable, communities that would fission again sooner. Which is the better option will depend on the exact trade-offs between these costs and benefits. The Hutterites seem to try to solve this dilemma by allowing community size to overrun the 150 mark somewhat before fissioning (but with ~200 as the normative upper limit: Fig. 2a). When they then fission, they do so unevenly, usually leaving the community that retains the parental farm (presumably the less stressful environment) with the less stable larger half.

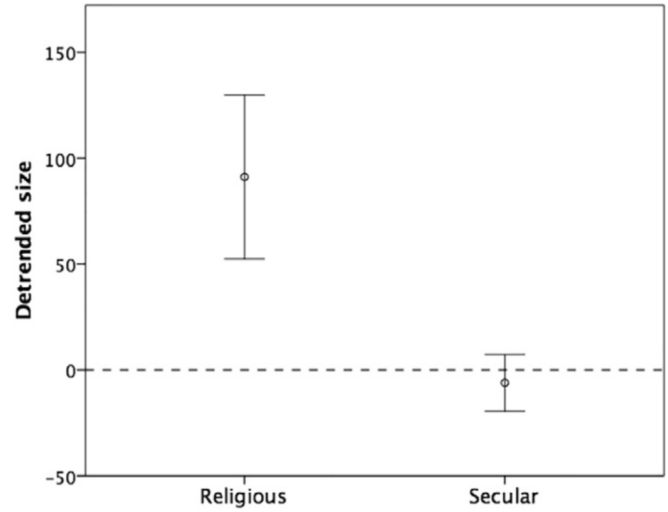

Fig. 4. Mean (± 1 se) residual community size, given time since foundation, for religious ($N = 15$) and secular ($N = 225$) kibbutzim.

The contrast between religious and secular communes in both the US and kibbutz samples suggests that a religious framework might provide a mechanism that allows a larger group of people to be held together (in the US case, effectively quadrupling the community's survival time compared to secular communities). One possible explanation is that a religious ideology somehow helps to keep a community better in tune with itself socially (Sosis & Ruffle, 2004). A moralizing 'high god' that acts as an all-seeing 'police force' (Purzycki et al., 2016) and religious obligations that foster self-control (Sosis & Ruffle, 2003; Ruffle & Sosis, 2007) may help to reinforce adherence to community rules. However, it may also be that a religious framework generates greater 'bottom-up' commitment to the ideals of the community, either by imposing high entry costs (what has to be given up to join) and/or on-going maintenance costs (e.g. attending religious rituals) or through personal ideological commitment (Near, 1997; Olsen, 1987; Sosis, 2000) such that individuals are more willing to tolerate the inevitable stresses of communal life.

In the absence of any relevant data either way, we assume that these communities are all substructured in much the same way that personal social networks and hunter-gatherer communities seem to be (Dunbar, 2011, 2014a, 2014b; Dunbar et al., 2015; MacCarron et al., 2016), and that this substructuring provides the fracture lines along which fission typically occurs. Lehmann et al. (2014) have suggested that, in hunter-gatherer societies, the layers or groupings created by this substructuring provide different kinds of functional benefits, and it may therefore be the balance between these different benefits in different contexts that pushes the communities in the present sample towards different optima under their very different economic circumstances.

With the exception of a few communes that required celibacy throughout their existence and did not adopt children, all of the communities we consider contain both adults and children. We may reasonably assume that the tensions that eventually give rise to community fission occur between adults, and hence that the effective functional group size is actually the number of adults. However, the routes by which conflict and stresses arise within communities can be complex. Evidence from primates, for example, suggests that the principal factor precipitating group fission may be stresses arising from female-female competition (Dunbar, 2017; Dunbar et al., submitted). Conflict between families over children, or at least conflict between the interests of one's children versus the interests of the community as a whole, may also be important for humans, and these can often be social (who has the right to discipline whose children). Since almost all analyses of social group size, in humans as well as nonhuman primates and other mammals, focus on total group size, we here simply follow common practice.

In sum, analyses of the size and fission patterns of small scale historical and contemporary farming communities suggest that there may be a set of natural optimal community sizes that approximate 50, 150 and 500, with deviations away from these values resulting in reduced functionality and increased risk of fission. Other contemporary cases in which functional unit size matches these values have been noted (e.g. the GoreTex company's preferred factory size of ~150: Gladwell, 2000; modern military organization: Dunbar, 2011). This may relate to the efficiency with which structural relationships function within small organisations and the ease with which stresses and destabilising events lead to loss of trust and commitment (Sutcliffe et al., 2012). An obvious direction for further work is whether these conclusions also apply to the structure of modern industrial, social, political and educational organisations.

Acknowledgments

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.evolhumbehav.2017.11.001.

References

Abramitzky, R. (2008). The limits of equality: Insights form the Israeli kibbutz. *Quarterly Journal of Economics*, *123*, 1111–1159.
Abramitzky, R. (2011). On the (lack of) stability of communes: An economic perspective. In R. M. McCleary (Ed.), *Handbook of the economics of religion* (pp. 169–189). Oxford: Oxford University Press.
Arnaboldi, V., Passarella, A., Conti, M., & Dunbar, R. I. M. (2015). *Online social networks: Human cognitive constraints in Facebook and Twitter personal graphs*. Amsterdam: Elsevier.
Ben-Rafael, E. (1997). *Crisis and transformation: The kibbutz at century's end*. New York: SUNY Press.
Blackburn, T. M., Lawton, J. H., & Perry, J. N. (1992). A method of estimating the slope of upper-bounds of plots of body size and abundance in natural animal assemblages. *Oikos*, *65*, 107–112.
Cowlishaw, G., & Dunbar, R. I. M. (2000). *Primate conservation biology*. Chicago, IL: Chicago University Press.
Dàvid-Barrett, T., & Dunbar, R. I. M. (2017). Fertility, kinship and the evolution of mass ideologies. *Journal of Theoretical Biology*, *417*, 20–27.
Dunbar, R. I. M. (1995). On the evolution of language and kinship. In J. Steele, & S. Shennan (Eds.), *The archaeology of human ancestry: Power, sex and tradition* (pp. 380–396). London: Routledge.
Dunbar, R. I. M. (2011). Constraints on the evolution of social institutions and their implications for information flow. *Journal of Institutional Economics*, *7*, 345–371.
Dunbar, R. I. M. (2012). Bridging the bonding gap: The transition from primates to humans. *Philosophical Transactions of the Royal Society of London*, *367B*, 1837–1846.
Dunbar, R. I. M. (2014a). The social brain: Psychological underpinnings and implications for the structure of organizations. *Current Directions in Psychological Science*, *24*, 109–114.
Dunbar, R. I. M. (2014b). Mind the gap: Or why humans aren't just great apes. In R. I. M. Dunbar, C. Gamble, & J. A. J. Gowlett (Eds.), *Lucy to language: The benchmark papers* (pp. 3–18). Oxford: Oxford University Press.
Dunbar, R. I. M. (2016). Do online social media cut through the constraints that limit the size of offline social networks? *Royal Society Open Science*, *3*, 150292.
Dunbar, R. I. M. (2017). Social structure as a strategy to mitigate the costs of group-living: A comparison of gelada and guereza monkeys. *Animal Behaviour* (in press).
Dunbar, R. I. M., Arnaboldi, V., Conti, M., & Passarella, A. (2015). The structure of online social networks mirrors those in the offline world. *Social Networks*, *43*, 39–47.
Dunbar, R. I. M., Korstjens, A. H., & Lehmann, J. (2009). Time as an ecological constraint. *Biological Reviews*, *84*, 413–429.
Dunbar, R.I.M., MacCarron, P., & Robertson, C.n.d. Tradeoff between fertility and predation risk drives a fractal pattern of group size in baboons. (submitted).
Forge, A. (1972). Normative factors in the settlement size of Neolithic cultivators (New Guinea). In P. Ucko, R. Tringham, & G. Dimbelby (Eds.), *Man, settlement and urbanisation*. London: Duckworth.
Fuchs, B., Sornette, D., & Thurner, S. (2014). Fractal multi-level organisation of human groups in a virtual world. *Scientific Reports*, *4*, 6526.
Gladwell, M. (2000). *The tipping point*. London: Little Brown.
Hamilton, M. J., Milne, B. T., Walker, R. S., Burger, O., & Brown, J. H. (2007). The complex structure of hunter – Gatherer social networks. *Proceedings of the Royal Society of London*, *274B*, 2195–2202.
Hill, R. A., & Dunbar, R. I. M. (2003). Social network size in humans. *Human Nature*, *14*, 53–72.
Kordsmeyer, T., MacCarron, P., & Dunbar, R. I. M. (2017). Sizes of permanent campsites reflect constraints on natural human communities. *Current Anthropology*, *58*, 289–294.
Lehmann, J., Lee, P. C., & Dunbar, R. I. M. (2014). Unravelling the evolutionary function of communities. In R. I. M. Dunbar, C. Gamble, & J. A. J. Gowlett (Eds.), *Lucy to language: The benchmark papers* (pp. 245–276). Oxford: Oxford University Press.
MacCarron, P., Kaski, K., & Dunbar, R. I. M. (2016). Calling Dunbar's numbers. *Social Networks*, *47*, 151–155.
Naroll, R. (1956). A preliminary index of social development. *American Anthropologist*, *58*, 687–715.
Near, H. (1997). *The kibbutz movement: A history. Crises and achievements, 1939–1995, Vol. 2.*London: Valentine Mitchell.
Olsen, C. L. (1987). The demography of colony fission from 1878–1970 among the Hutterites of North America. *American Anthropologist*, *89*, 823–837.
Oved, Y. (1988). *Two hundred years of American communes*. New Brunswick, NJ: Transaction Books.
Pavin, A. (2007). *The kibbutz movement: Fact and figures*. Ramat Efal: Yad Tabenkin.
Purzycki, B. G., Apicella, C., Atkinson, Q. D., Cohen, E., Mcnamara, R. A., Willard, A. K., ... Henrich, J. (2016). Moralistic gods, supernatural punishment and the expansion of human sociality. *Nature*, *530*, 327–330.
Roberts, S. B. G., Dunbar, R. I. M., Pollet, T., & Kuppens, T. (2009). Exploring variations in active network size: Constraints and ego characteristics. *Social Networks*, *31*, 138–146.
Ruffle, B. J., & Sosis, R. (2007). Does it pay to pray? Costly ritual and cooperation. *The BE Journal of Economic Analysis & Policy*, *7*, 18.
Sosis, R. (2000). Religion and intragroup cooperation: Preliminary results of a comparative analysis of utopian communities. *Cross-Cultural Research*, *34*, 70–87.
Sosis, R., & Bressler, E. R. (2003). Cooperation and commune longevity: A test of the costly signaling theory of religion. *Cross-Cultural Research*, *37*, 211–239.
Sosis, R., & Ruffle, B. J. (2003). Religious ritual and cooperation: Testing for a relationship on Israeli religious and secular kibbutzim. *Current Anthropology*, *44*, 713–722.
Sosis, R., & Ruffle, B. J. (2004). Ideology, religion, and the evolution of cooperation: Field experiments on Israeli kibbutzim. *Research in Economic Anthropology*, *23*, 89–117.
Sutcliffe, A. J., Dunbar, R. I. M., Binder, J., & Arrow, H. (2012). Relationships and the social brain: Integrating psychological and evolutionary perspectives. *British Journal of Psychology*, *103*, 149–168.
Zhou, W. -X., Sornette, D., Hill, R. A., & Dunbar, R. I. M. (2005). Discrete hierarchical organization of social group sizes. *Proceedings of the Royal Society of London*, *272B*, 439–444.